The Effect of STEM Learning with Interactive Quiz Gamification on Elementary School Students' Scientific Literacy: A Quasi-Experimental Study

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Abstract. This study aims to examine the effect of STEM learning assisted by interactive gamification-based quizzes on elementary school students' science literacy. This research employed a quantitative approach with a quasi-experimental design using a nonequivalent control group design. The sample consisted of 60 students, divided into an experimental group and a control group. The experimental group received STEM learning assisted by interactive gamification-based quizzes, while the control group was taught using conventional methods. The results showed that the mean score of the experimental group increased from 64.33 (pretest) to 84.43 (posttest), while the control group increased from 62.10 to 73.28. The paired samples t-test indicated a significant difference ($p = 0.000 < 0.05$), and the independent samples t-test also showed a significant difference between groups ($p = 0.000 < 0.05$) with a mean difference of 11.16. In addition, the N-Gain score of 0.56 was categorized as moderate. These findings indicate that STEM learning assisted by interactive gamification-based quizzes is effective in improving students' science literacy. Therefore, this approach can be recommended as an innovative strategy to enhance science learning in elementary schools.

Keywords: STEM learning, gamification, interactive quizzes, science literacy, elementary school.

1. Introduction

The advancement of science and technology in the 21st century requires students to possess critical, creative, collaborative, and communicative thinking skills as part of the core competencies that must be developed from the elementary level [1-3]. One of the essential abilities in facing these challenges is scientific literacy, which includes the ability to understand scientific concepts, interpret data, and apply scientific knowledge responsibly in everyday life [4-6]. Scientific literacy is not only oriented toward content mastery but also toward the development of scientific thinking and contextual problem-solving skills [7-8].

However, various international reports, such as the Programme for International Student Assessment (PISA), indicate that the level of students' scientific literacy in Indonesia remains relatively low [9]. This low level of scientific literacy is partly due to learning practices that are still teacher-centered and provide limited opportunities for students to actively engage in the processes of exploration and concept discovery [10;

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4; 11]. In addition, science learning in elementary schools often lacks the integration of multiple disciplines, making it difficult for students to understand the connection between learned concepts and real-life contexts.

As a solution, the STEM (Science, Technology, Engineering, and Mathematics) approach has been widely recommended as an alternative in modern education [12-13]. The STEM approach integrates these four disciplines in a unified manner within real-world problem-solving contexts, thereby promoting higher-order thinking skills and enhancing students' scientific literacy [14-17]. Through STEM learning, students are encouraged to actively explore, design, and test solutions to given problems, making the learning process more meaningful and contextual [18-19]. Numerous studies have shown that the implementation of STEM learning can improve students' understanding of scientific concepts, critical thinking skills, and scientific literacy [20-21]. Furthermore, STEM provides authentic learning experiences through the integration of technology and engineering practices in instruction [22-23]. Nevertheless, the implementation of STEM in elementary schools still faces several challenges, such as low student engagement and a lack of varied and engaging instructional strategies.

In this context, the integration of gamification into STEM learning emerges as an innovative strategy to enhance student motivation and engagement. Gamification refers to the application of game elements such as points, levels, challenges, and instant feedback, into the learning process to create a more interactive and enjoyable learning experience [24-25]. One practical form of gamification is the use of game-based interactive quizzes, which can effectively encourage active student participation [26-27].

Previous studies have demonstrated that the use of gamification in learning can significantly improve learning motivation, student engagement, and learning outcomes [28]. In science education, gamification also contributes to improving conceptual understanding and critical thinking skills through challenging, problem-based activities. Therefore, integrating STEM learning with gamified interactive quizzes has great potential to enhance students' scientific literacy more effectively.

However, studies that specifically examine the effect of STEM learning assisted by gamified interactive quizzes on elementary school students' scientific literacy are still limited. Most existing research tends to focus on either STEM or gamification separately, thus failing to provide a comprehensive understanding of the effectiveness of integrating these two approaches. This indicates a research gap that needs further investigation.

Based on the above explanation, this study aims to analyze the effect of STEM learning assisted by gamified interactive quizzes on the scientific literacy of elementary school students. This study employs a quasi-experimental design to test the effectiveness of the proposed approach. The findings of this study are expected to contribute to the development of innovative learning models and serve as a reference for educators in improving the quality of science learning at the elementary school level.

2. Research Method

2.1 Research Design

This study employed a quantitative approach with a quasi-experimental design aimed at determining the effect of STEM learning assisted by gamified interactive quizzes on elementary school students' scientific literacy. The research design used was a nonequivalent control group design, involving two groups: an experimental group and a control group. Both groups were given a pretest and a posttest; however, only the experimental group received the treatment in the form of STEM learning assisted by gamified interactive quizzes, while the control group was taught using conventional learning methods.

2.2 Research Subjects

The subjects of this study were elementary school students consisting of two classes. One class was assigned as the experimental group, and the other class as the control group. The number of samples in each group was 30 students, resulting in a total sample of 60 students. The sampling technique used was purposive sampling, with consideration given to the equivalence of students' initial abilities based on the pretest results.

2.3 Research Procedure

This study was conducted through three main stages: the preparation stage, the implementation stage, and the final stage. In the preparation stage, the researcher developed STEM-based learning materials integrated with gamified interactive quizzes, constructed scientific literacy test instruments, and prepared digital learning media such as interactive quiz platforms. In addition, the research instruments were tested for validity and reliability to ensure their appropriateness in measuring students' scientific literacy.

In the implementation stage, both the experimental and control groups were first given a pretest to determine students' initial scientific literacy abilities. Subsequently, the experimental group received treatment in the form of STEM learning assisted by gamified interactive quizzes, which involved activities such as exploration, problem-solving, discussion, and the use of game-based quizzes to enhance student engagement. Meanwhile, the control group received conventional teacher-centered instruction. After the entire learning process was completed, both groups were given a posttest to measure the improvement in students' scientific literacy.

In the final stage, the researcher collected all pretest and posttest data, followed by data processing and analysis to test the research hypothesis. The results of the analysis were used to draw conclusions regarding the effect of STEM learning assisted by gamified interactive quizzes on elementary school students' scientific literacy.

2.4 Data Collection Techniques

The data collection technique in this study used tests as the primary instrument to measure students' scientific literacy. The test consisted of multiple-choice questions developed based on scientific literacy indicators, including the ability to understand concepts, analyze information, and apply knowledge in real-life contexts. The test was administered in two stages: a pretest before the treatment to determine students' initial abilities, and a posttest after the treatment to measure the improvement in scientific literacy.

In addition, data collection was supported by documentation used to complement information related to the learning process, such as the number of students, classroom conditions, and the implementation of learning activities during the study.

2.5 Data Analysis Techniques

The data analysis techniques in this study involved both descriptive and inferential statistical analyses. Descriptive analysis was used to describe the research data through the calculation of the mean, standard deviation, and variance of the pretest and posttest results in both groups. This analysis aimed to provide a general overview of the improvement in students' scientific literacy.

Furthermore, inferential analysis was conducted to test the research hypothesis. Prerequisite tests were first carried out, including the normality test using Shapiro–Wilk to determine data distribution, and the homogeneity test using Levene's test to assess the equality of variances between groups.

After meeting these assumptions, a paired samples t-test was conducted to determine the difference between pretest and posttest scores in the experimental group, along with the calculation of N-Gain to measure the level of improvement in students' scientific literacy. In addition, an independent samples t-test was used to determine the difference in posttest results between the experimental and control groups. All data analyses were performed using statistical software with a significance.

3. Result & Discussion

This study aims to determine the improvement of students' scientific literacy through the implementation of different instructional approaches in the experimental and control groups. The experimental group was treated with STEM learning assisted by gamified interactive quizzes, while the control group received conventional learning. To examine the initial and final profiles of students' scientific literacy abilities, descriptive statistical analysis was conducted on the pretest and posttest results of both groups.

The results of the descriptive analysis, including the mean, standard deviation, and variance, are presented in Table 1.

Table 1. Descriptive Statistics of Science Literacy

Group	Mean	Std. Deviation	Variance
Pretest Experimental	64.33	7.06	49.82
Posttest Experimental	84.43	9.87	97.50
Pretest Control	62.10	6.37	40.60
Posttest Control	73.28	12.55	157.42

Based on Table 1, the descriptive statistics reveal an improvement in students' science literacy scores in both the experimental and control groups. In the experimental group, which was taught using STEM learning assisted by interactive gamification-based quizzes, the mean score increased significantly from 64.33 in the pretest to 84.43 in the posttest, indicating a substantial enhancement following the intervention. In contrast, the control group, which received conventional instruction, also showed an increase in mean scores from 62.10 to 73.28; however, the magnitude of improvement was notably lower than that observed in the experimental group.

The difference in students' scientific literacy mean scores can be visualized in the following figure.

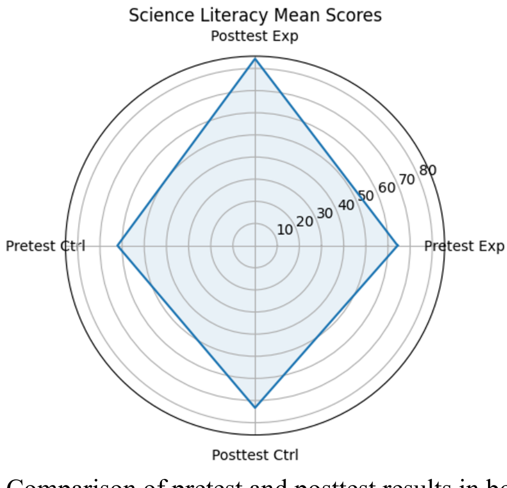

Figure 1. Comparison of pretest and posttest results in both groups

Before conducting the hypothesis test, a normality test was first performed to determine whether the data were normally distributed. The results of the normality test are presented in Table 2.

Table 2. Normality Test Results

Group	Sig.
Pretest Experimental	0.184
Posttest Experimental	0.390
Pretest Control	0.584
Posttest Control	0.920

Based on Table 2, the results of the Shapiro–Wilk normality test indicate that all data are normally distributed. This is evidenced by the significance values of all groups being greater than 0.05. Specifically, the pretest experimental group has a significance value of 0.184, the posttest experimental group 0.390, the pretest control group 0.584, and the posttest control group 0.920.

After confirming that the data meet the assumption of normality, the next step in the analysis is to examine the homogeneity of variance. The homogeneity test is conducted to determine whether the variances between groups are equal, which is an important assumption for applying parametric tests such as the independent samples t-test. In this study, the homogeneity of variance was tested using Levene's Test. The results of the homogeneity test are presented in Table 3.

Table 3. Homogeneity Test Results

		Levene Statistic	Sig.
Science Literacy	Based on Mean	1.905	.173
	Based on Median	1.850	.179
	Based on Median and with adjusted df	1.850	.179
	Based on trimmed mean	1.849	.179

Based on Table 3, the results of Levene's Test show that the significance value based on the mean is 0.173, which is greater than 0.05. These results indicate that the variance of science literacy scores between groups is homogeneous. Therefore, the assumption of homogeneity of variance is satisfied, and parametric tests can be appropriately conducted.

After confirming that the data meet both normality and homogeneity assumptions, the next step is to examine the differences between pretest and posttest scores within the same group. This analysis is conducted using a paired samples t-test to determine whether there is a significant improvement in students' science literacy after the implementation of the learning intervention. The results of the paired samples t-test are presented in Table 4.

Table 4. Paired Samples t-Test Results

Comparison	**Mean Difference**	**t**	**Sig. (2-tailed)**
Pretest – Posttest	-20.10	-10.326	0.000

Based on Table 4, the results of the paired samples t-test indicate a statistically significant difference between pretest and posttest scores ($p = 0.000 < 0.05$). The mean difference of -20.10 indicates that the posttest scores are considerably higher than the pretest scores, reflecting a substantial improvement in students' science literacy following the implementation of STEM learning assisted by interactive gamification-based quizzes. These findings confirm that the applied learning intervention has a significant effect on enhancing students' science literacy.

However, while the paired samples t-test confirms the existence of a significant difference, it does not provide sufficient information regarding the magnitude or effectiveness of the improvement achieved. Therefore, further analysis using the normalized gain (N-Gain) was conducted to evaluate the effectiveness of the STEM-based gamified learning intervention in improving students' science literacy. The results of the N-Gain analysis are presented in Table 5.

Table 5. Descriptive Statistics of N-Gain Scores

Variable	N	Mean	Std. Deviation	Category
N-Gain	30	0.56	0.28	Moderate

Based on Table 5, the descriptive statistics of the N-Gain scores show a mean value of 0.56, which falls into the moderate category. This indicates that the improvement in students' science literacy after the implementation of STEM learning assisted by interactive gamification-based quizzes is at a moderate level. The N-Gain values range from -0.03 to 1.00, suggesting that although most students experienced improvement, there is considerable variation in the extent of their learning gains. The standard deviation of 0.28 further reflects a moderate dispersion of scores, indicating differences in how effectively students benefited from the intervention.

Overall, these findings suggest that the integration of STEM learning with gamified interactive quizzes is moderately effective in enhancing students' science literacy. The variation in N-Gain scores may be influenced by factors such as students' initial ability levels, engagement during the learning process, and adaptability to technology-enhanced instruction.

After examining the improvement within the experimental group, the next step is to determine whether there is a statistically significant difference in science literacy between the experimental group, which received the STEM-based gamified learning intervention, and the control group, which was taught using conventional methods. This comparison is conducted using an independent samples t-test based on the posttest scores of both groups. The results of the independent samples t-test are presented in Table 6.

Table 6. Independent Samples t-Test Results

Comparison	t	Sig. (2-tailed)	Mean Difference
Experimental vs Control	3.803	0.000	11.16

Based on Table 6, the results of the independent samples t-test indicate a statistically significant difference between the experimental and control groups ($p = 0.000 < 0.05$). This finding demonstrates that there is a significant difference in students' science literacy between the two groups following the implementation of the learning intervention.

The mean difference of 11.16 indicates that the experimental group, which was taught using STEM learning assisted by interactive gamification-based quizzes, achieved higher science literacy scores compared to the control group, which received conventional instruction. This suggests that the applied intervention is more effective in enhancing students' science literacy than traditional teaching approaches.

The results of the study indicate that STEM learning assisted by gamified interactive quizzes has a significant effect on improving elementary school students' scientific literacy. This is evidenced by the greater increase in pretest to posttest scores in the experimental group compared to the control group, and is further supported by statistical test results showing significant differences between the groups. These findings suggest that the integration of the STEM approach with gamification strategies can create a more effective and meaningful learning experience for students.

The improvement in scientific literacy in the experimental group can be explained by the characteristics of STEM learning, which emphasize the integration of science, technology, engineering, and mathematics in real-world problem-solving contexts. This approach encourages students to actively engage in exploration, think critically, and apply concepts in contextual situations [29];[16];[15]. In line with this, previous studies have stated that STEM learning can enhance higher-order thinking skills and students' scientific literacy through investigative and project-based activities [17];[30].

In addition, the use of gamification in the form of interactive quizzes also contributed significantly to the improvement of students' learning outcomes. Gamification introduces game elements such as challenges, points, and immediate feedback, which can enhance students' motivation and engagement in learning [31-32]. In this context, students are not only passive recipients of information but also active participants who are engaged in the learning process in an enjoyable and competitive manner. Previous research also shows that gamification can increase student participation and strengthen conceptual understanding through more intensive interaction with learning materials [24].

The findings of this study are further supported by the N-Gain analysis results, which fall into the moderate category, indicating that STEM learning assisted by gamified interactive quizzes is sufficiently effective in improving students' scientific literacy. However, variations in N-Gain scores indicate differences in the level of improvement among students. This may be influenced by several factors, such as students' initial abilities, their level of engagement in learning, and their ability to adapt to the use of technology. Therefore, although the approach is generally effective, attention to individual student characteristics is still necessary in its implementation.

Furthermore, the results of the independent samples t-test show that the experimental group achieved significantly higher scientific literacy scores compared to the control group. This confirms that STEM learning assisted by gamified interactive quizzes is more effective than conventional learning, which tends to be teacher-centered. Conventional learning generally provides fewer opportunities for students to actively engage in the learning process, which in turn affects their ability to understand and apply scientific concepts.

Thus, this study implies that the integration of STEM learning with gamified interactive quizzes can serve as an alternative innovative instructional strategy to improve elementary school students' scientific literacy. This approach not only enhances learning outcomes but also creates a more active, enjoyable, and meaningful learning environment. However, this study has several limitations, including the limited sample size and the specific school context, which means that the generalization of the findings should be made with caution. Therefore, future research is recommended to involve a larger sample and to examine other variables that may influence the effectiveness of the learning approach.

4. Conclusion

This study concludes that the implementation of STEM learning assisted by interactive gamification-based quizzes has a significant and positive effect on improving elementary school students' science literacy. The results show that the mean score in the experimental group increased from 64.33 in the pretest to 84.43 in the posttest, while the control group increased from 62.10 to 73.28. This indicates that the improvement in the experimental group is substantially higher than in the control group.

The statistical analysis further supports these findings, as the paired samples t-test shows a significant difference ($p = 0.000 < 0.05$), and the independent samples t-test also indicates a significant difference between groups ($p = 0.000 < 0.05$) with a mean difference of 11.16. Additionally, the N-Gain score of 0.56 in the experimental group falls into the moderate category, indicating a moderate level of effectiveness of the implemented learning approach.

Overall, the integration of STEM learning with gamified interactive quizzes creates a more engaging and effective learning environment, making it a recommended instructional strategy for improving students' science literacy. Future research is suggested to involve larger samples and longer intervention periods to further validate these findings.

Authors' Contributions

All authors contributed to this study. The first author conducted the research and wrote the manuscript, while the other authors contributed to data analysis, review, and editing. All authors approved the final version.

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